NASA TECHNICAL MEMORANDUM

NASA TM X-1019

STABILITY AND CONTROL CHARACTERISTICS OF A MANNED LIFTING ENTRY VEHICLE AT MACH NUMBERS FROM 2.29 TO 4.63

by John T. McShera, Jr., and James F. Campbell

Langley Research Center
Langley Station, Hampton, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • OCTOBER 1964

UNCLASSIFIED

~~CONFIDENTIAL~~

CLASSIFICATION CHANGED

To UNCLASSIFIED

By authority of CSTAR Date 12-31-70
V.8 No. 24
Blm
3-18-71

STABILITY AND CONTROL CHARACTERISTICS OF A MANNED LIFTING ENTRY VEHICLE AT MACH NUMBERS FROM 2.29 TO 4.63

By John T. McShera, Jr., and James F. Campbell

Langley Research Center
Langley Station, Hampton, Va.

GROUP 4
Downgraded at 3 year intervals;
declassified after 12 years

CLASSIFIED DOCUMENT–TITLE UNCLASSIFIED

This material contains information affecting the national defense of the United States within the meaning of the espionage laws, Title 18, U.S.C., Secs. 793 and 794, the transmission or revelation of which in any manner to an unauthorized person is prohibited by law.

NOTICE

This document should not be returned after it has satisfied your requirements. It may be disposed of in accordance with your local security regulations or the appropriate provisions of the Industrial Security Manual for Safe-Guarding Classified Information.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

UNCLASSIFIED

~~CONFIDENTIAL~~

UNCLASSIFIED

STABILITY AND CONTROL CHARACTERISTICS OF A MANNED LIFTING ENTRY VEHICLE AT MACH NUMBERS FROM 2.29 TO 4.63*

By John T. McShera, Jr., and James F. Campbell
Langley Research Center

SUMMARY

An investigation has been made in the Langley Unitary Plan wind tunnel to determine the stability and control characteristics of a manned lifting entry configuration designated HL-10 at Mach numbers from 2.29 to 4.63. The results indicated that within the trim angle-of-attack range, the vehicle was longitudinally stable and had good pitch-control effectiveness for all test Mach numbers. The maximum trim lift-drag ratio was approximately 1.4 and varied little between angles of attack of 15° to 30° over the entire Mach number range.

The basic configuration was directionally stable at a Mach number of 4.63 but became directionally unstable in the approximate angle-of-attack range of maximum lift-drag ratio at the lowest test Mach number. Roll-control effectiveness appears to be good in the high angle-of-attack range; however, the rudder control effectiveness is zero.

INTRODUCTION

Configurations having moderate lift-drag ratios (on the order of 1.0) are of considerable interest for future entry vehicles. However, because these entry configurations are required to operate over a wide range of angles of attack and Mach numbers during the entry mode, some problems in stability and control may arise. One of these configurations is undergoing concentrated study at the Langley Research Center (refs. 1, 2, and 3). It, as well as some other lifting entry vehicles (see, for instance, ref. 4), may depend largely upon aerodynamic controls for the principal flight control system.

The present investigation was made through a Mach number range of 2.29 to 4.63 to determine the stability and control characteristics of the cambered HL-10 lifting entry configuration having dorsal and tip fins. (See refs. 2 and 3.) The tests were performed in the Langley Unitary Plan wind tunnel at angles of attack from -5° to 62° at angles of sideslip of 0° and 5°.

---

*Title, Unclassified.

[redacted]

UNCLASSIFIED

SYMBOLS

The results are presented as force and moment coefficients; lift, drag, and pitching moment are referred to the stability axis system and rolling moment, yawing moment, and side force are referred to the body axis system. The reference center of moments was located at 53 percent of the body length aft of the nose, and at 1.25 percent of the body length below the body reference line. The symbols used are defined as follows:

b	body reference span, 10.310 in.
l	body reference length, 16.00 in.
L	lift
D	drag
L/D	lift-drag ratio
C_L	lift coefficient, $\frac{\text{Lift}}{qS}$
C_D	drag coefficient, $\frac{\text{Drag}}{qS}$
C_m	pitching-moment coefficient, $\frac{\text{Pitching moment}}{qSl}$
C_l	rolling-moment coefficient, $\frac{\text{Rolling moment}}{qSb}$
C_{l_β}	effective dihedral parameter, $\Delta C_l/\Delta\beta$
C_n	yawing-moment coefficient, $\frac{\text{Yawing moment}}{qSb}$
C_{n_β}	directional stability parameter, $\Delta C_n/\Delta\beta$
C_Y	side-force coefficient, $\frac{\text{Side force}}{qS}$
C_{Y_β}	lateral-force parameter, $\Delta C_Y/\Delta\beta$
M	free-stream Mach number
q	free-stream dynamic pressure

R radius, in.

S reference planform area, 0.634 sq ft

x,y,z distances along X, Y, and Z axes, respectively, in.

α angle of attack referred to body reference line, deg

α_{nom} angle of attack not corrected for flow angularity

β angle of sideslip referred to plane of symmetry, deg

δ_e resultant angle of pitch control flap (positive when trailing edge is down), $\dfrac{\delta_{e_{right}} + \delta_{e_{left}}}{2}$, deg

δ_a resultant angle of roll control flap (positive when trailing edge is down on the right or up on the left), $\delta_{e_{right}} - \delta_{e_{left}}$, deg

δ_r angle of rudder control (positive when trailing edge is deflected to left when viewed from rear), deg

TEST CONDITIONS

The test conditions are summarized in the following table:

Mach number	Stagnation temperature, °F	Stagnation pressure, lb/sq ft abs	Reynolds number/ft
2.29	150	1,986	2.6×10^6
2.96	150	2,880	2.6
3.96	175	4,970	2.6
4.63	175	7,150	2.6

The stagnation dewpoint was maintained at -30° F in order to avoid condensation effects in the test section. Angles of attack and sideslip were corrected for deflection of the balance and sting support under load. The data have also been corrected for flow angularity. The drag data presented are those measured during the investigation. No adjustment has been made to relate drag levels to a condition corresponding to free-stream static-pressure conditions at the model base.

Aerodynamic forces and moments were measured by a six-component electrical strain-gage balance housed within the model. The balance, in turn, was rigidly fastened to a sting support and thence to the tunnel support system. The angle-of-attack range of the tests extended from about -5° to 62° at angles of sideslip of about 0° and 5°.

The accuracy of the measured quantities, based on calibration and repeatability of data, is estimated to be within the following limits:

C_L	±0.002
C_D	±0.001
C_m	±0.002
C_l	±0.002
C_n	±0.001
C_Y	±0.001
α, deg	±0.10
β, deg	±0.10
Mach numbers: 2.29 and 2.96	±0.015
Mach numbers: 3.96 and 4.63	±0.05

MODEL AND APPARATUS

Details of the model are presented in figure 1 and ordinates defining the profile and cross-section shape of the model are given in table I. A photograph of the model is shown in figure 2.

The model has a leading-edge sweep angle of 74°. Directional stability is provided by two tip fins oriented at approximately 30° away from the vertical and a third fin (vertical) located on the body upper surface in the plane of symmetry. The ratio of total tip-fin area projected to the plane of symmetry relative to configuration planform area is 0.0595. The center vertical fin has a ratio of side area to model planform area of 0.0739. The ratios of the planform area of the pitch controls and the side area of the yaw control to model planform area are 0.1099 and 0.0126, respectively.

Flap control to provide longitudinal and lateral trim is derived from four deflectable elevons. The elevons are deflected in pairs on either side of the plane of symmetry and are located on the upper and lower surfaces of the basic body at the trailing edge. (See figs. 1 and 2.) Zero angle on all control surfaces is defined as that condition where the surface is in line with the normal contours of elements of the model immediately upstream of the surface. Directional control is obtained by deflection of each of two movable rudders at the trailing edge of the center vertical fin. Toed rudder deflection is opposite deflection of each panel on the center fin.

The tip fins used in the tests were designated by D-1 and the center fin was designated by E (refs. 2 and 3). Tests were conducted in the high Mach number test section of the Langley Unitary Plan wind tunnel, which is a variable-pressure, continuous-flow tunnel. (See ref. 5.) The test section is 4 feet square and 7 feet long. The nozzle leading to the test section is of the asymmetric, sliding-block type which permits a continuous variation in test-section Mach number from about 2.3 to 4.7.

PRESENTATION OF RESULTS

The results of this investigation are presented in the following figures:

	Figure
Schlieren photographs	3
Longitudinal characteristics of the model with various deflections of the elevons for longitudinal control. $\delta_r = \delta_a = 0^\circ$	4
Longitudinal characteristics of the model with toed rudder controls. $\delta_e = \delta_a = 0^\circ$	5
Lateral stability characteristics of the model. $\delta_e = \delta_a = 0^\circ$	6
Lateral characteristics of the model with various deflections of the elevons for roll control. $\delta_r = 0^\circ$	7
Lateral characteristics of the model with various deflections of the rudder. $\delta_e = \delta_a = 0^\circ$	8

The tip fins were on the model unless otherwise noted.

RESULTS AND DISCUSSION

The important stability condition shown by the pitch characteristics (fig. 4) is that the configuration is stable within the test trim angle-of-attack range at all Mach numbers investigated. It is to be noted that an apparent reduction in stability at the highest negative values of pitching moment (indicated by ticks on the curves) is the result of fouling of the model with the support system and is not indicative of the true aerodynamic characteristics. The values of C_L, C_D, and L/D were also affected by fouling.

The results indicate good longitudinal control effectiveness at all Mach numbers throughout the trim angle-of-attack range. It should be noted that the negative control deflection, although less effective in some angle-of-attack ranges and Mach numbers than positive control deflections, is sufficiently effective to assure aerodynamic trim and maneuverability at angles of attack that include maximum lift-drag ratio and nearly maximum lift coefficient.

The maximum trim lift-drag ratio was approximately 1.4 and varied little between angles of attack of 15° to 30° over the entire Mach number range. Deflecting the elevons has no significant effect on maximum lift-drag ratio.

Addition of the rolled-out fins (fig. 5) increases the longitudinal stability level slightly, due to increased stabilizing area added by the fin roll orientation. In addition, maximum lift-drag ratio is decreased slightly. The contribution of the rolled-out tip fins to directional stability (fig. 6) is also appreciable and increases with angle of attack but is not sufficient to make the vehicle directionally stable at all angles of attack at the low Mach numbers. Deflection of the toed rudder controls, which were designed to improve the directional stability, had no effect on the longitudinal characteristics (fig. 5) but had a small effect (sometimes detrimental) on the directional stability (fig. 6).

At the higher angle of attack, the vehicle has positive effective dihedral over the entire Mach number range. The tip fins contribute significantly to the effective dihedral. For example, at 45° angle of attack, about 40 percent of the dihedral effect is due to the tip fins.

Roll control effectiveness (fig. 7) appears to be good in the high angle-of-attack range. The effectiveness of the rudder (fig. 8) as a directional control device is high at the low angles of attack; however, with increases in angle of attack and Mach number, the local dynamic pressure is reduced and the rudder effectiveness becomes zero. In figures 7 and 8, C_l and C_n should be equal to zero over the entire angle-of-attack range for the controls at zero deflection. The differences noted are probably due to model inconsistencies in the plane of symmetry.

CONCLUSIONS

An investigation has been made in the Langley Unitary Plan wind tunnel of the longitudinal and lateral stability and control characteristics of a manned lifting entry vehicle designated HL-10 over a Mach number range from 2.29 to 4.63. The results of this investigation indicate the following conclusions:

1. The vehicle is longitudinally stable and has good pitch-control effectiveness within the trim angle-of-attack range for all test Mach numbers.

2. The maximum trim lift-drag ratio was approximately 1.4 and varied little between angles of attack of 15° to 30° over the entire Mach number range.

3. The basic configuration is directionally stable at a Mach number of 4.63 but becomes directionally unstable in the approximate angle-of-attack range of maximum lift-drag ratio at the lowest test Mach number.

4. In general, roll-control effectiveness increases and yaw-control effectiveness decreases with angle of attack, particularly at the highest Mach number.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., April 13, 1964.

REFERENCES

1. Rainey, Robert W., and Ladson, Charles L.: Preliminary Aerodynamic Characteristics of a Manned Lifting Entry Vehicle at a Mach Number of 6.8. NASA TM X-844, 1963.

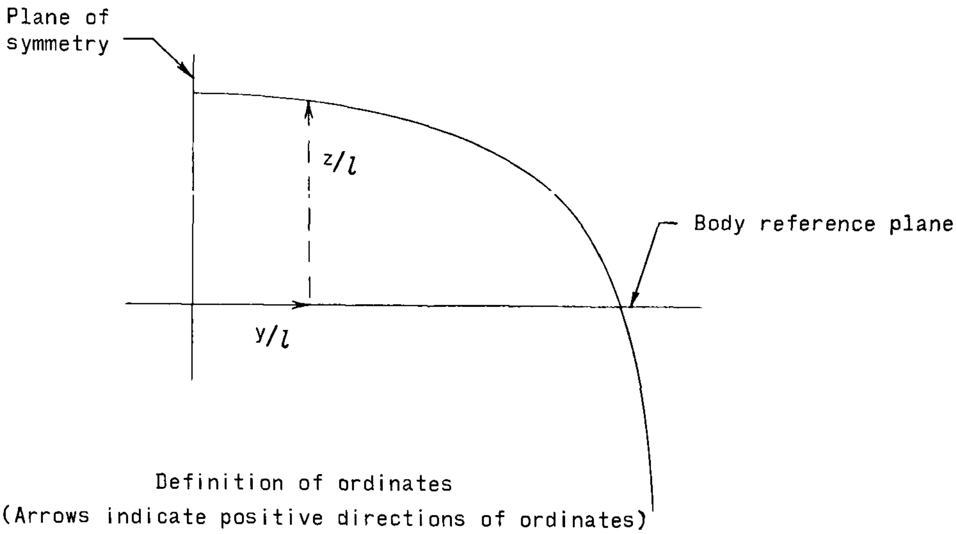
2. Ladson, Charles L.: Aerodynamic Characteristics of a Manned Lifting Entry Vehicle at a Mach Number of 6.8. NASA TM X-915, 1964.

3. Ware, George M.: Aerodynamic Characteristics of Models of Two Thick 74° Delta Manned Lifting Entry Vehicles at Low-Subsonic Speeds. NASA TM X-914, 1964.

4. Silvers, H. Norman, and Lowery, Jerry L.: Stability and Control Characteristics of a Flat-Bottom Lifting Reentry Configuration at a Mach Number of 1.61. NASA TM X-981, 1964.

5. Anon.: Manual for Users of the Unitary Plan Wind Tunnel Facilities of the National Advisory Committee for Aeronautics. NACA, 1956.

TABLE I.- MODEL CROSS-SECTION ORDINATES



Definition of ordinates
(Arrows indicate positive directions of ordinates)

Ordinates for x/l of -													
0.125		0.250		0.375		0.500		0.625		0.750		0.875	
y/l	z/l	y/l	z/l	y/l	z/l	y/l	z/l	y/l	z/l	y/l	z/l	y/l	z/l
0	0.0739	0	0.0809	0	0.0814	0	0.0814	0	0.0814	0	0.0814	0	0.0818
.0156	.0711	.0156	.0796	.0156	.0809	.0156	.0803	.0156	.0793	.0156	.0793	.0156	.0795
.0132	.0620	.0312	.0759	.0312	.0799	.0312	.0784	.0312	.0731	.0312	.0705	.0312	.0700
.0469	.0436	.0469	.0686	.0469	.0771	.0469	.0771	.0469	.0711	.0469	.0643	.0469	.0550
.0625	.0093	.0625	.0568	.0625	.0728	.0625	.0751	.0625	.0705	.0625	.0628	.0625	.0488
.0658	0	.0781	.0390	.0781	.0661	.0781	.0718	.0781	.0693	.0781	.0625	.0781	.0488
.0684	-.0156	.0938	.0093	.0938	.0558	.0938	.0676	.0938	.0675	.0938	.0621	.0938	.0488
.0696	-.0312	.0976	0	.1094	.0398	.1094	.0621	.1094	.0653	.1094	.0611	.1094	.0488
.0699	-.0424	.1015	-.0156	.1250	.0139	.1250	.0540	.1250	.0620	.1250	.0600	.1250	.0488
0	-.0899	.1040	-.0312	.1301	0	.1406	.0411	.1406	.0573	.1406	.0586	.1406	.0488
		.1054	-.0469	.1344	-.0156	.1563	.0210	.1563	.0505	.1563	.0568	.1563	.0488
		.1060	-.0670	.1375	-.0312	.1651	0	.1719	.0414	.1719	.0543	.1719	.0488
		0	-.1201	.1398	-.0469	.1694	-.0156	.1875	.0270	.1875	.0511	.1875	.0488
				.1411	-.0625	.1725	-.0312	.2045	0	.2031	.0464	.2031	.0488
				.1419	-.0783	.1749	-.0469	.2088	-.0156	.2188	.0386	.2188	.0488
				0	-.1328	.1764	-.0625	.2115	-.0312	.2344	.0261	.2344	.0488
						.1769	-.0775	.2130	-.0469	.2480	0	.2500	.0488
						0	-.1281	.2134	-.0561	.2496	-.0156	.2656	.0478
								0	-.1075	0	-.0790	.2813	.0468
												.2859	0
												0	-.0456

[redacted]

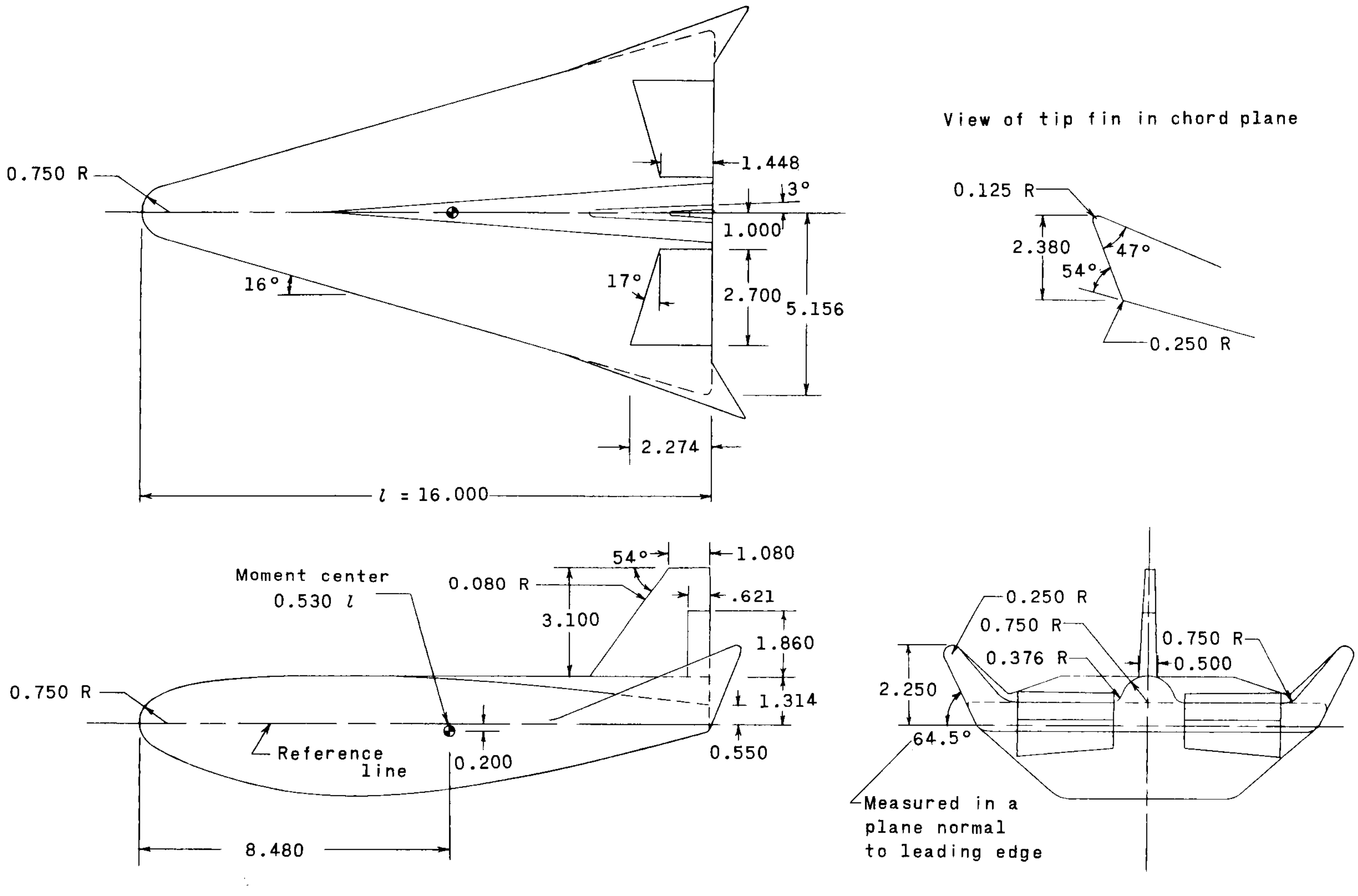


Figure 1.- Drawing of the test model. (All dimensions are in inches unless otherwise specified.)

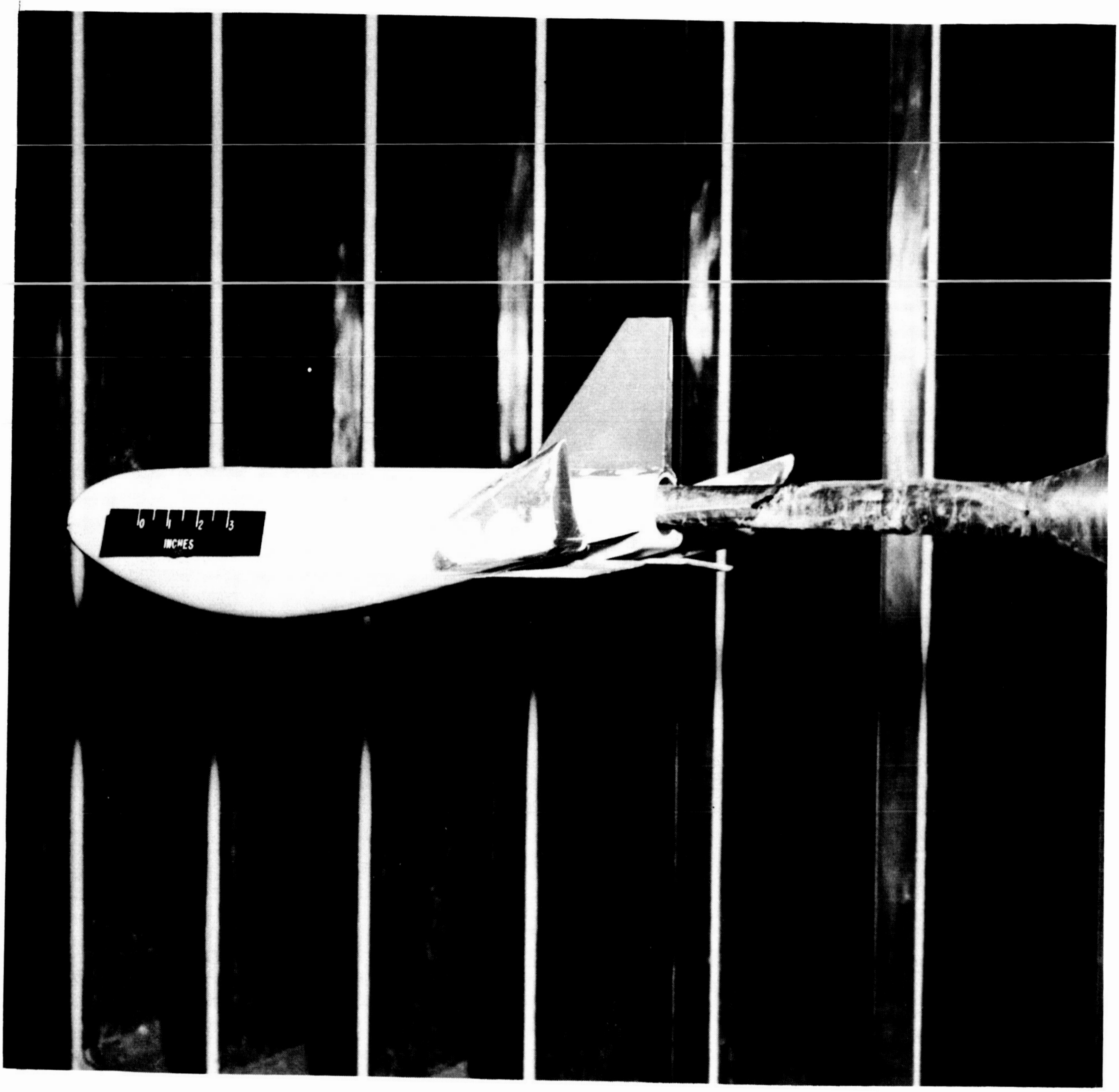


Figure 2.- Photograph of model. L-64-2960

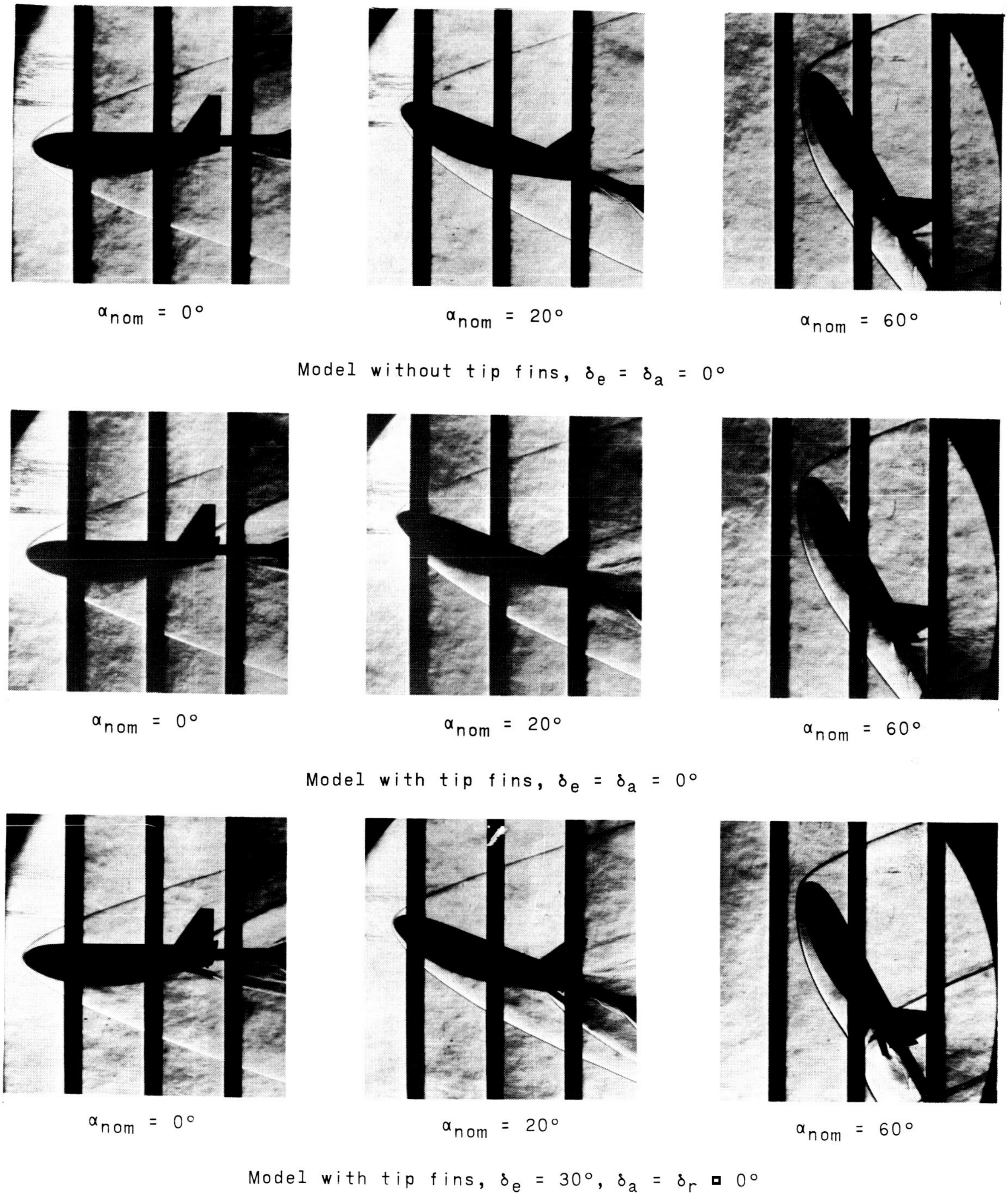
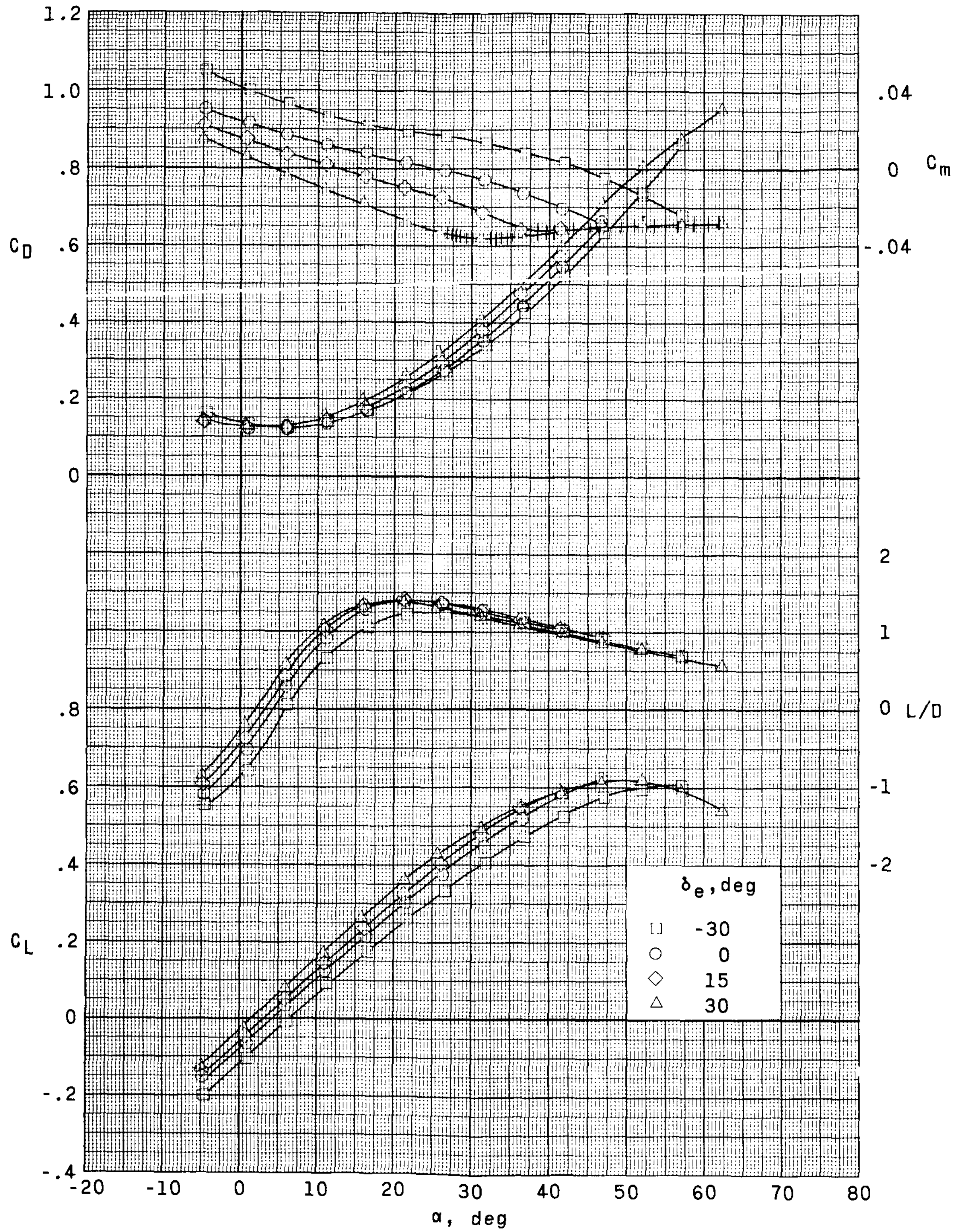
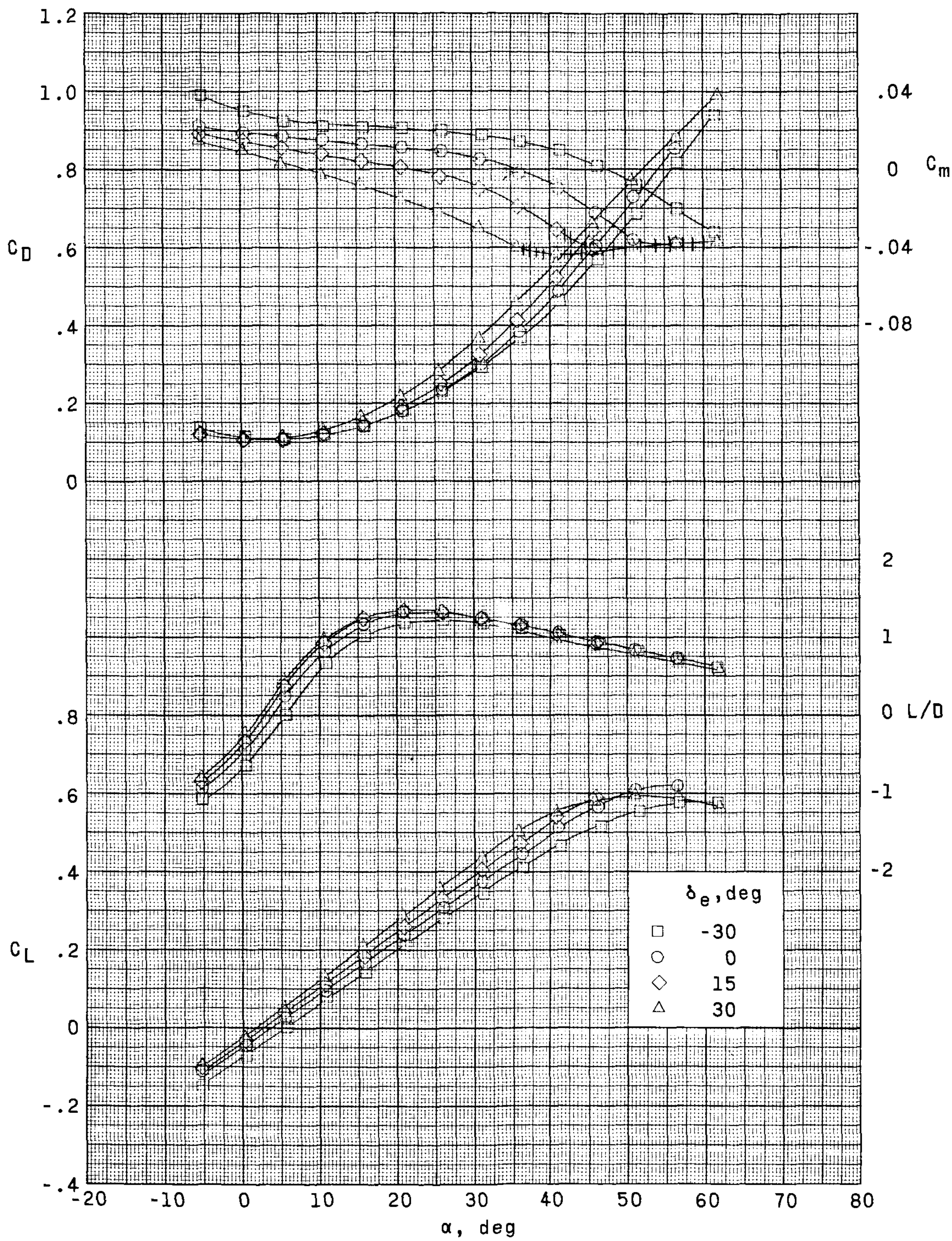


Figure 3.- Typical schlieren photographs at $M = 3.95$. L-64-3039



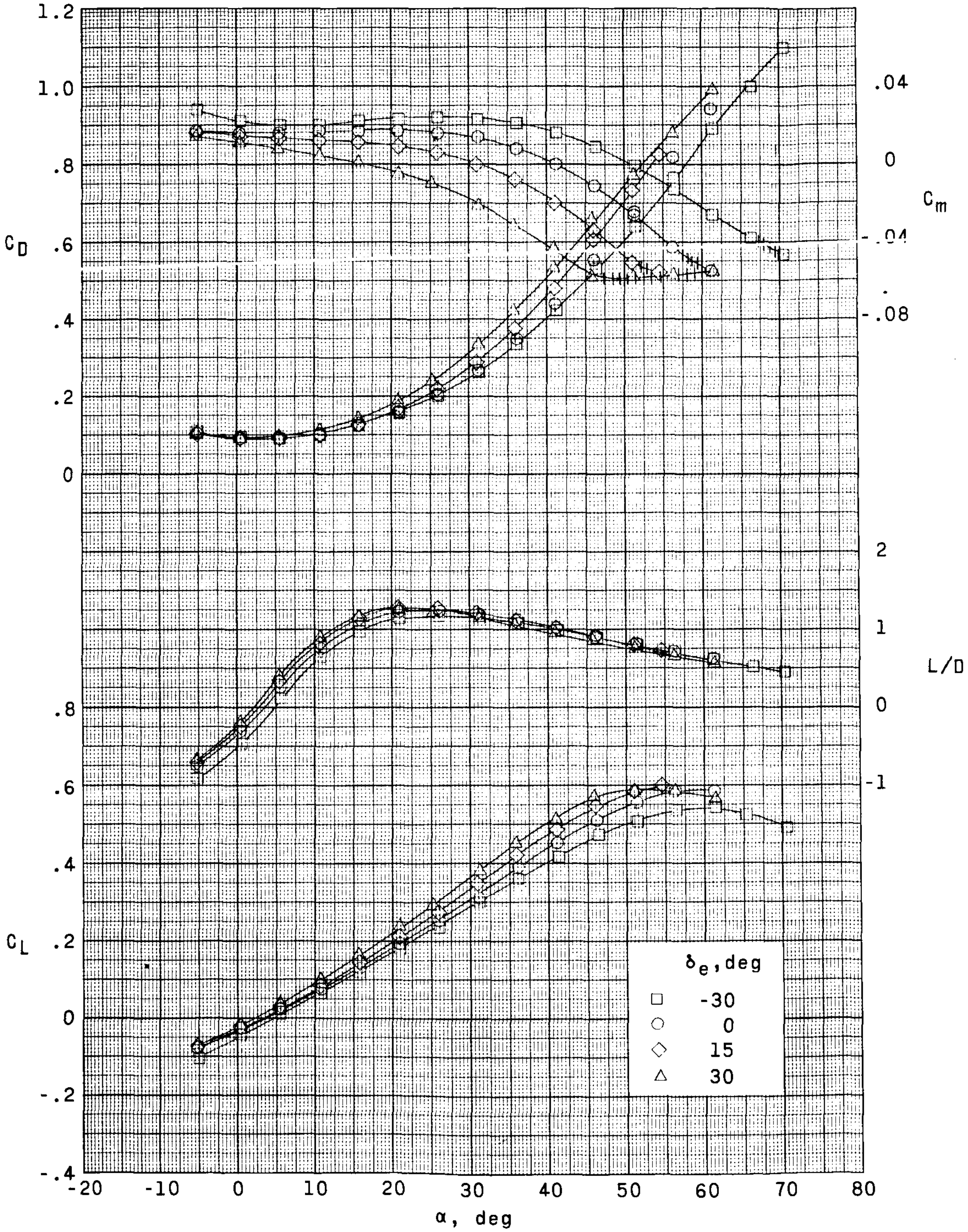
(a) $M = 2.29$.

Figure 4.- Longitudinal characteristics of the model with various deflections of the elevons for longitudinal control. $\delta_r = \delta_a = 0^{\circ}$.



(b) M = 2.96.

Figure 4.- Continued.

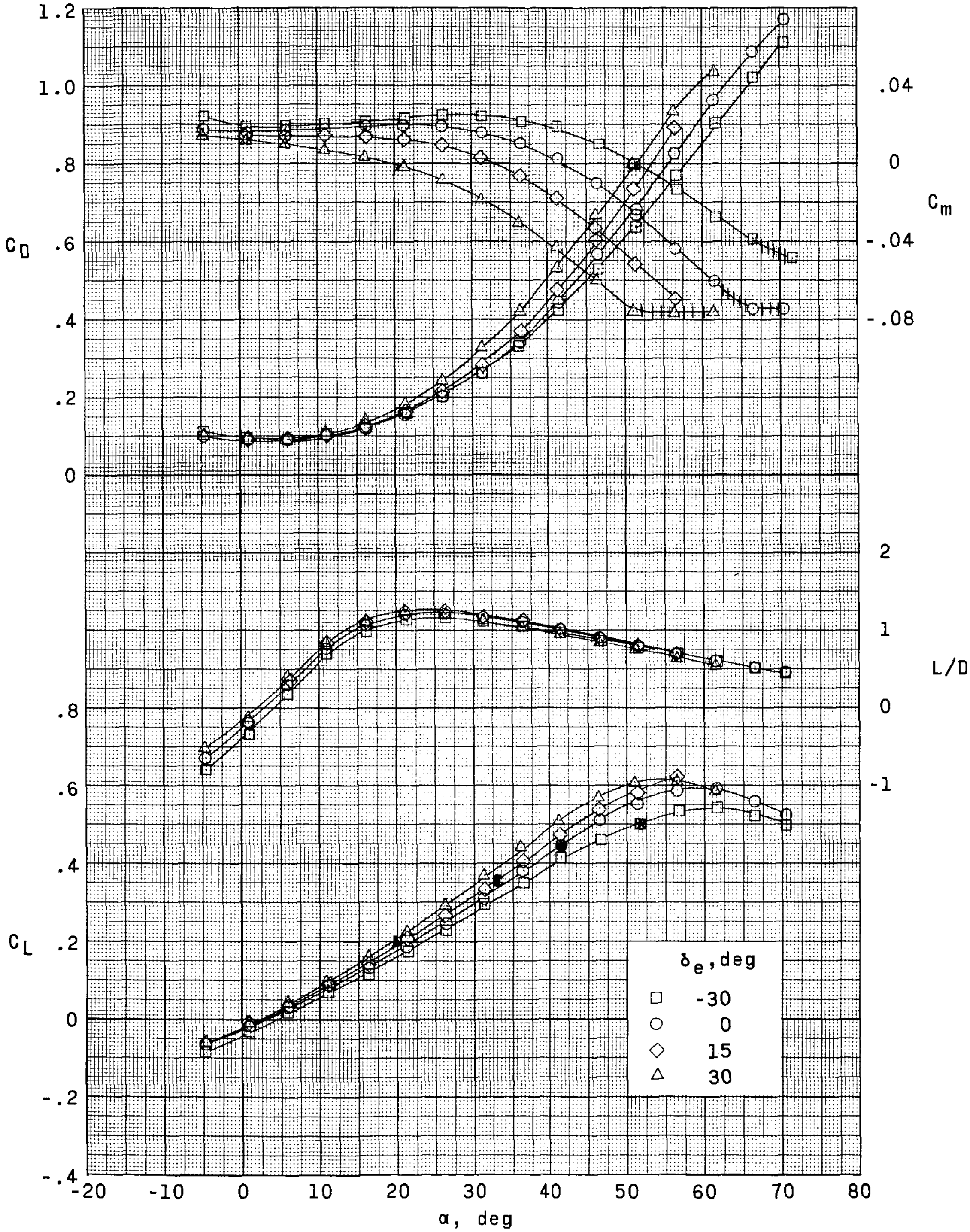


(c) M = 3.95.

Figure 4.- Continued.

UNCLASSIFIED

[redacted]

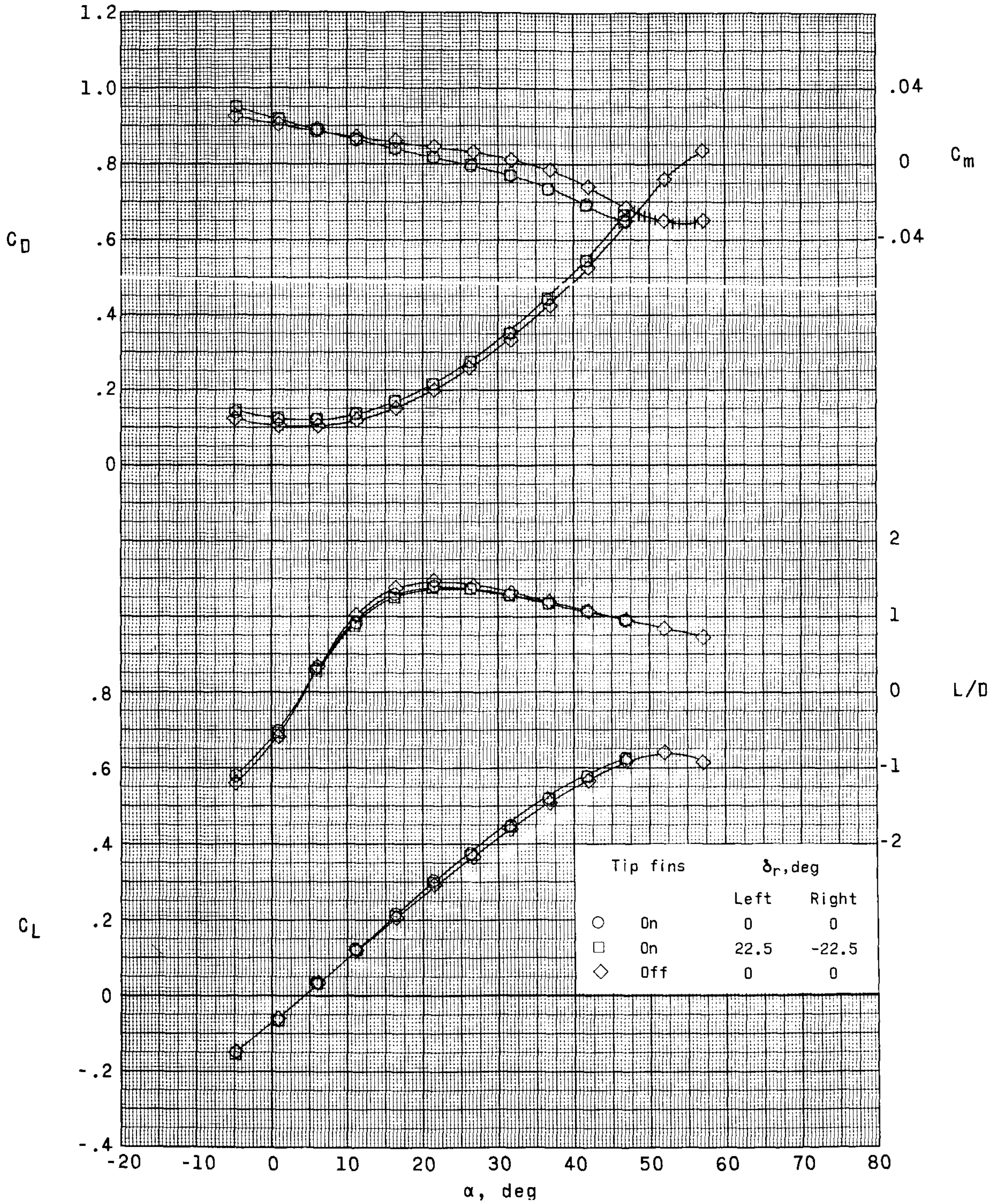


(d) M = 4.63.

Figure 4.- Concluded.

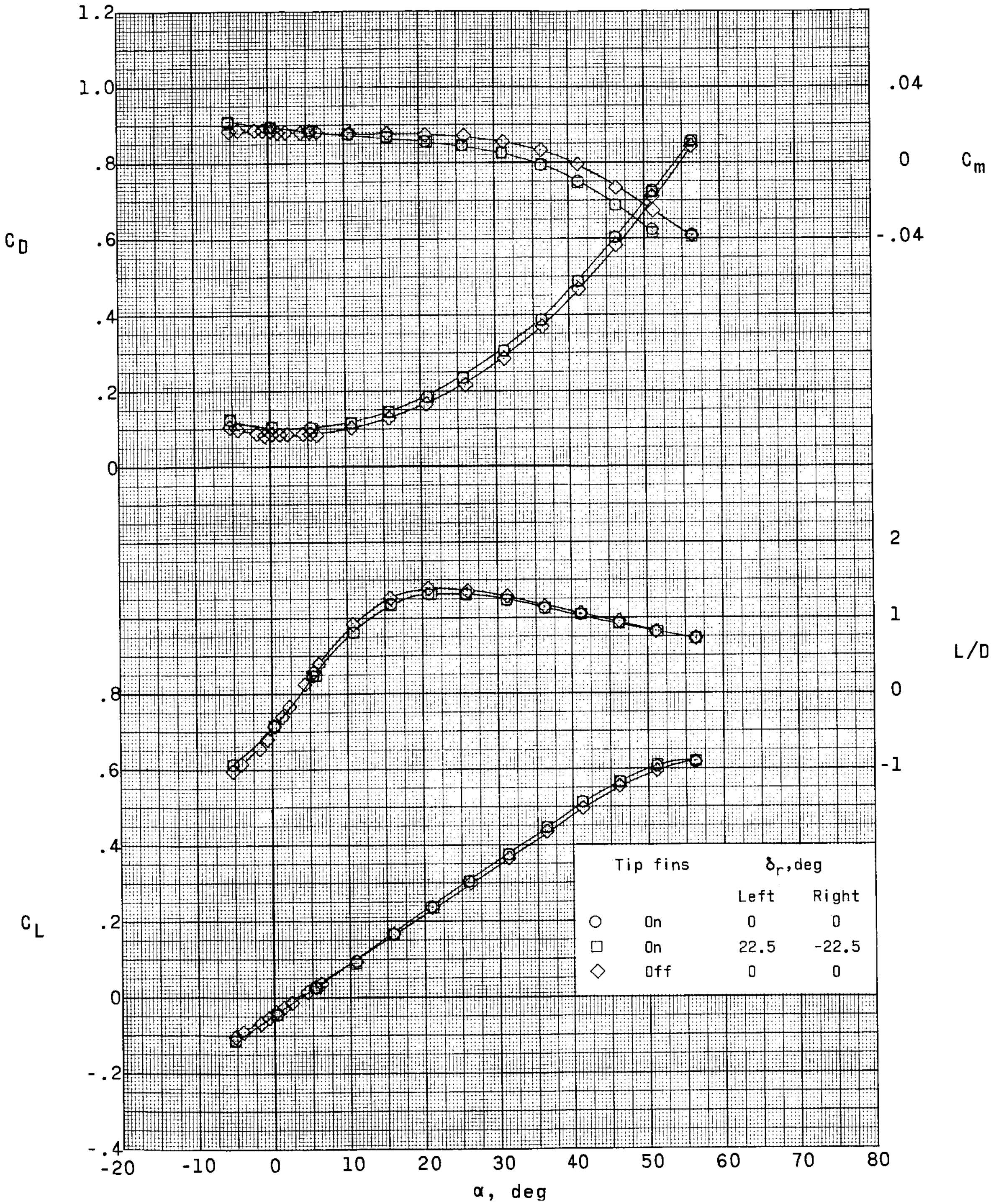
[redacted]

UNCLASSIFIED



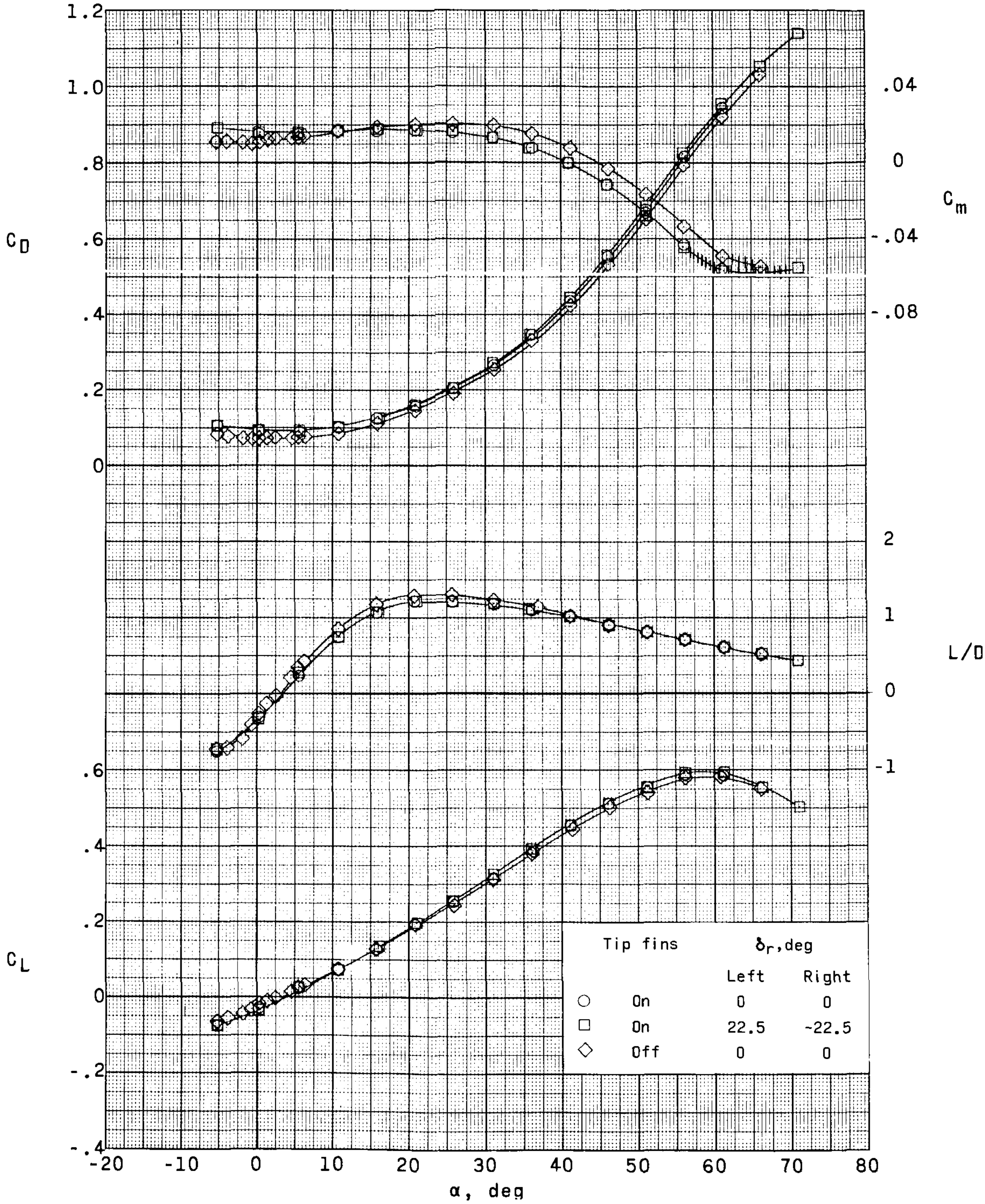
(a) $M = 2.29$.

Figure 5.- Longitudinal characteristics of the model with toed rudder controls. $\delta_e = \delta_a = 0^{\circ}$.



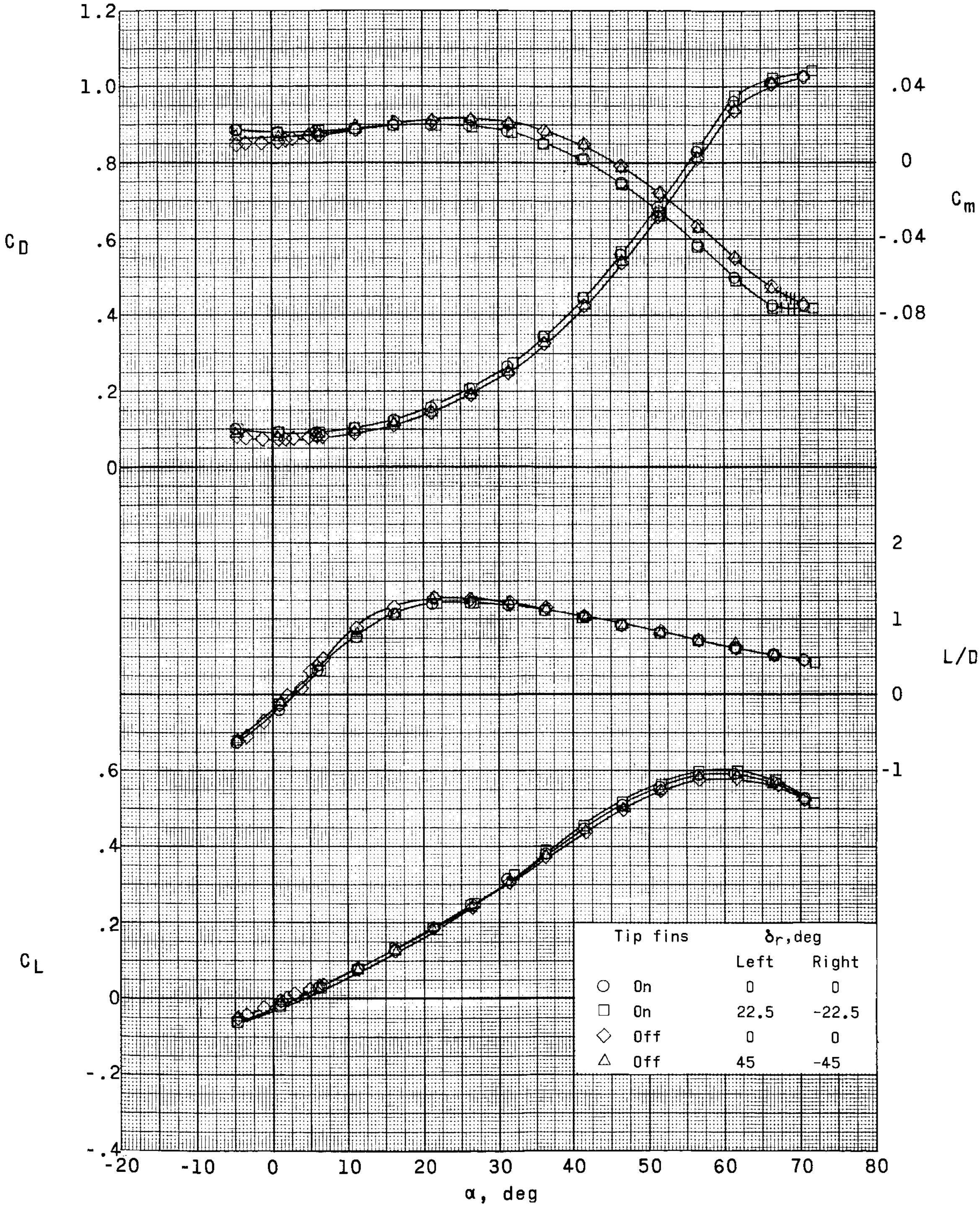
(b) M = 2.96.

Figure 5.- Continued.



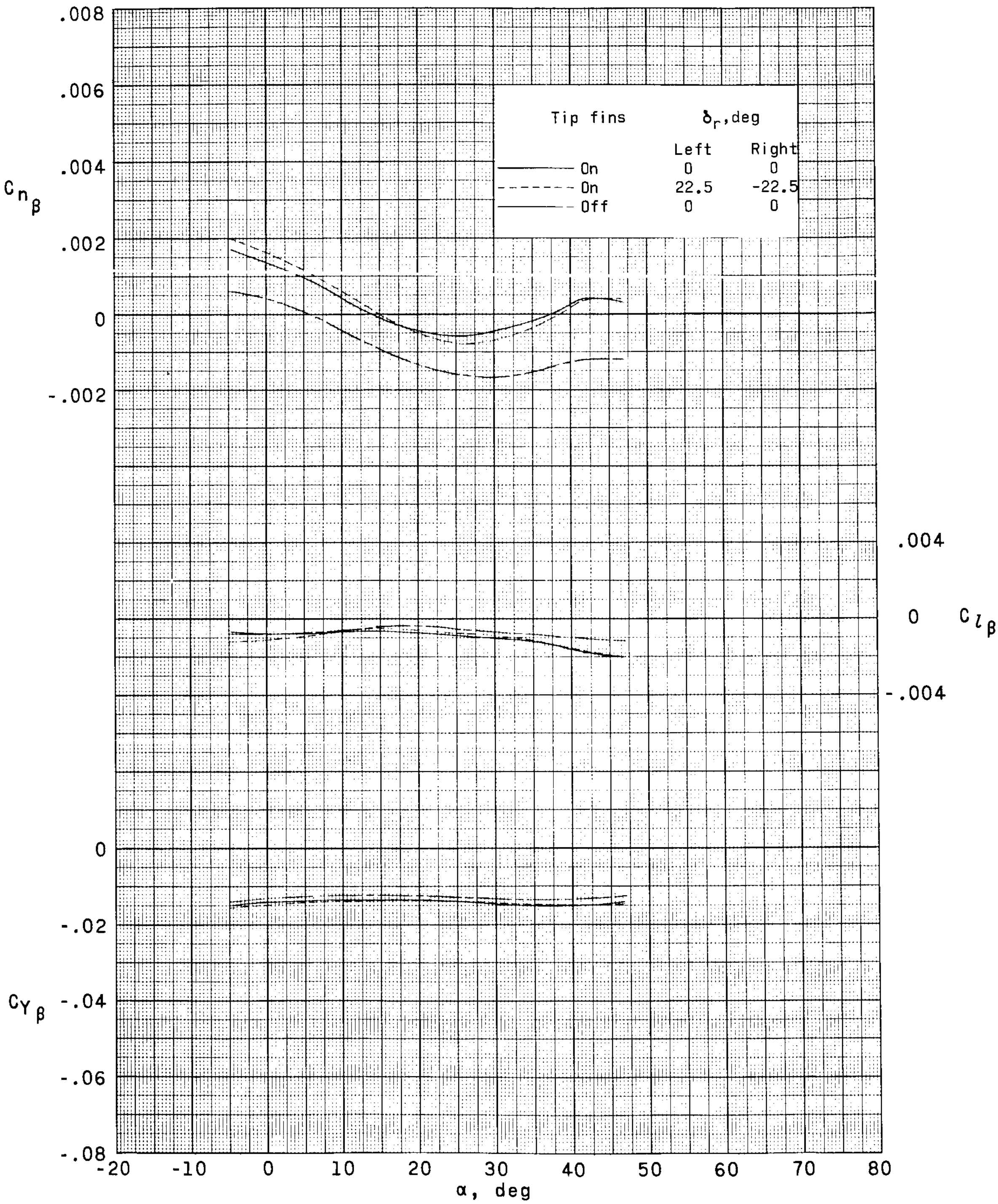
(c) M = 3.95.

Figure 5.- Continued.



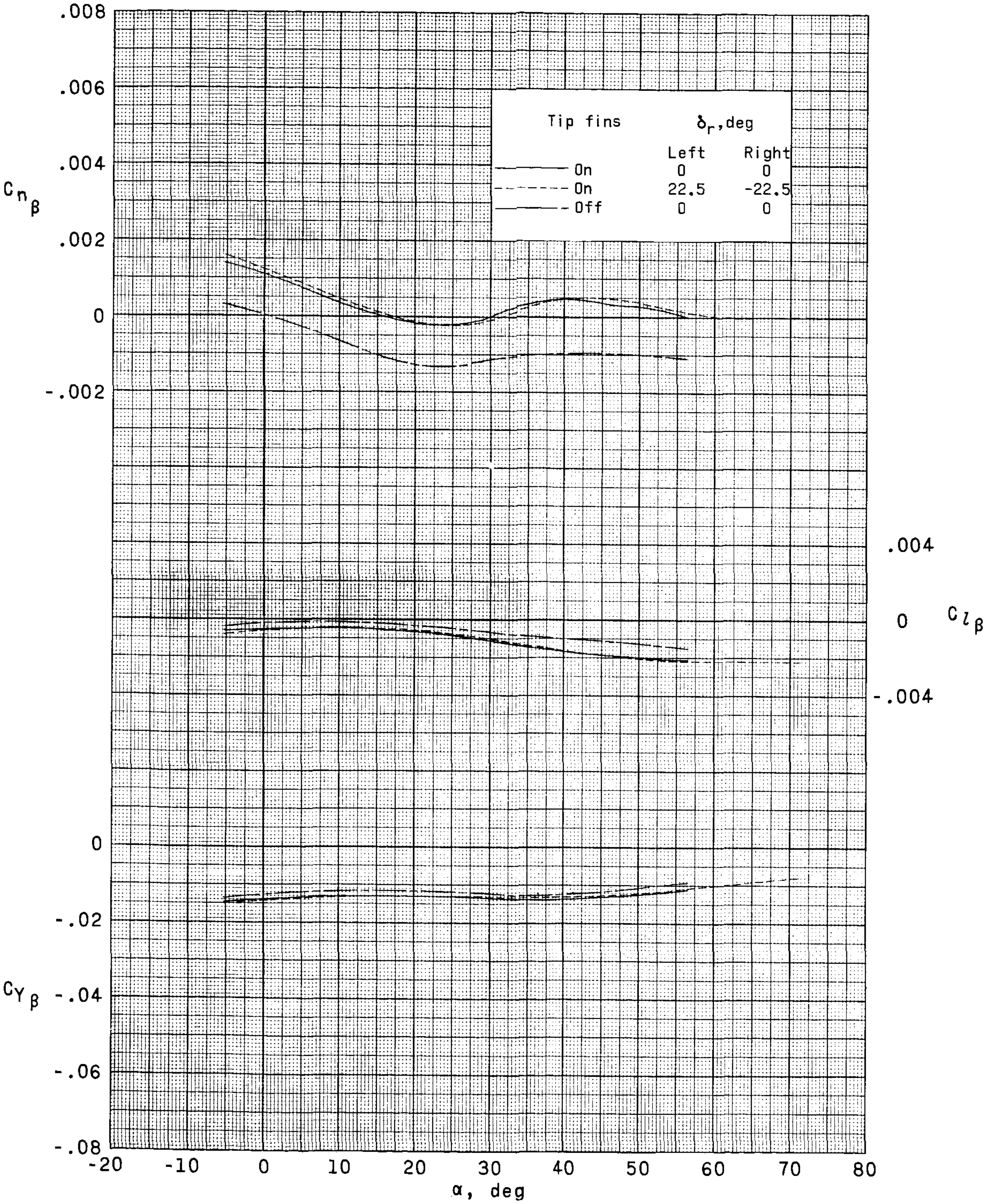
(d) M = 4.63.

Figure 5.- Concluded.



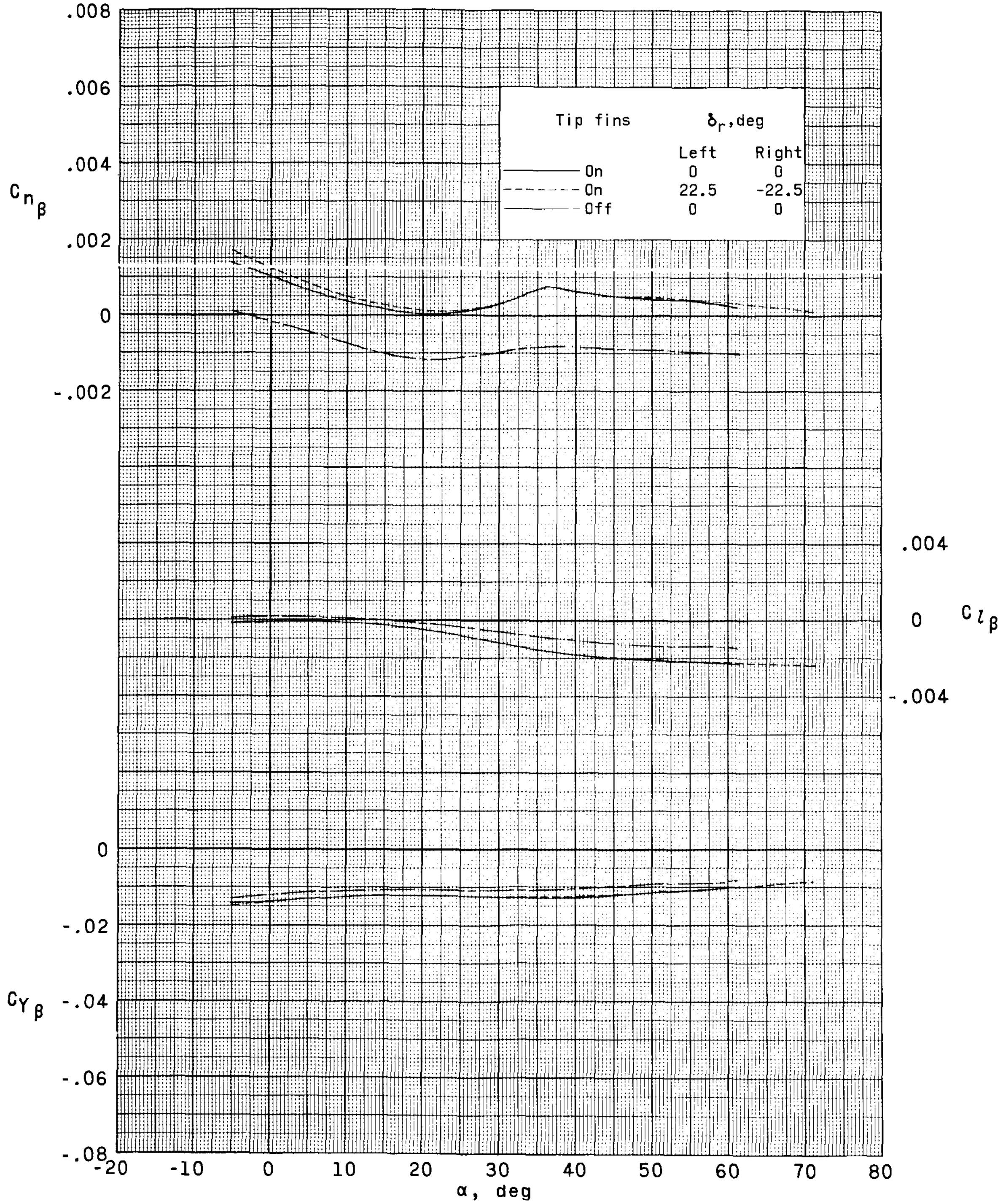
(a) M = 2.29.

Figure 6.- Lateral stability characteristics of the model. $\delta_e = \delta_a = 0^{\circ}$.



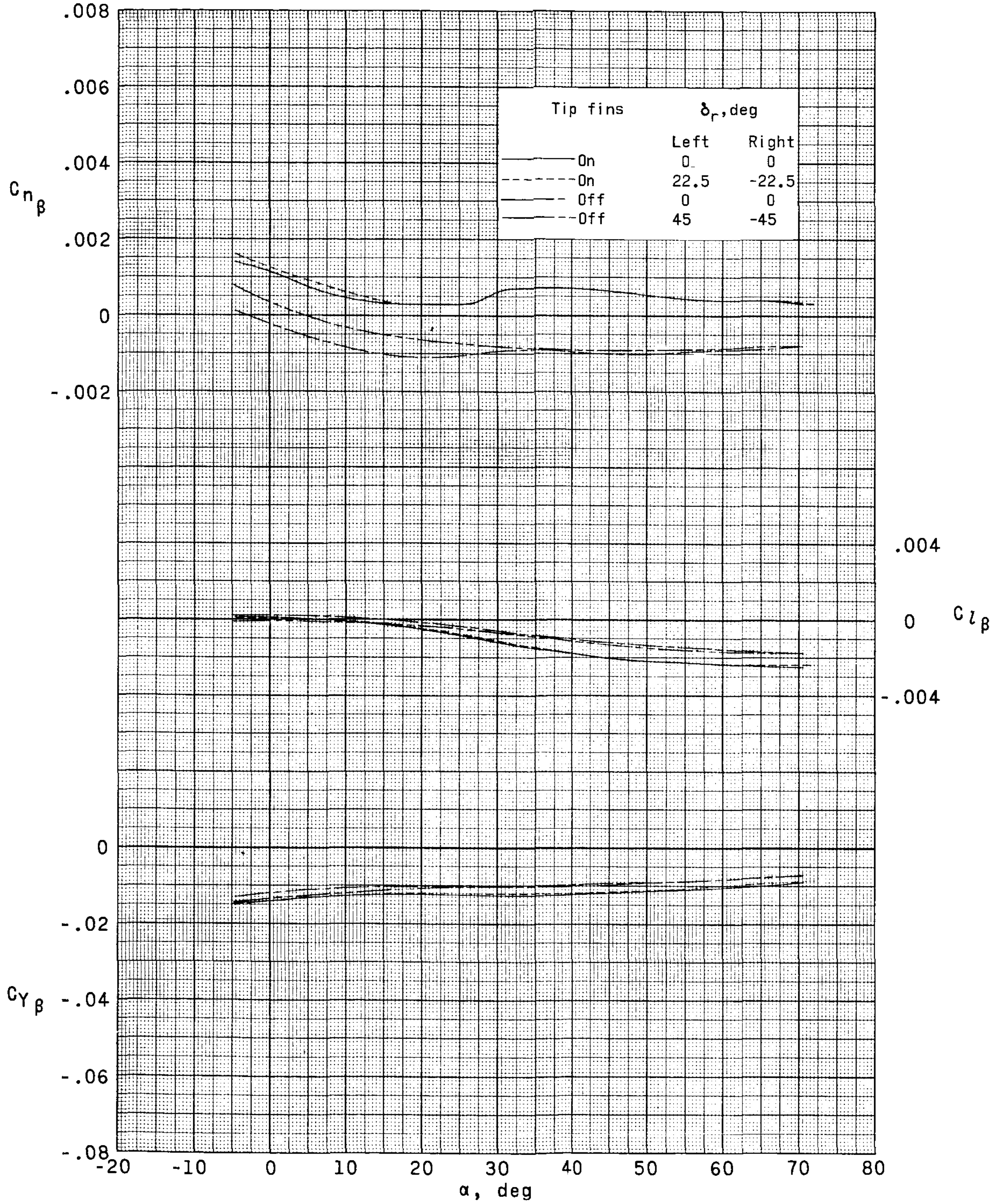
(b) M = 2.96.

Figure 6.- Continued.



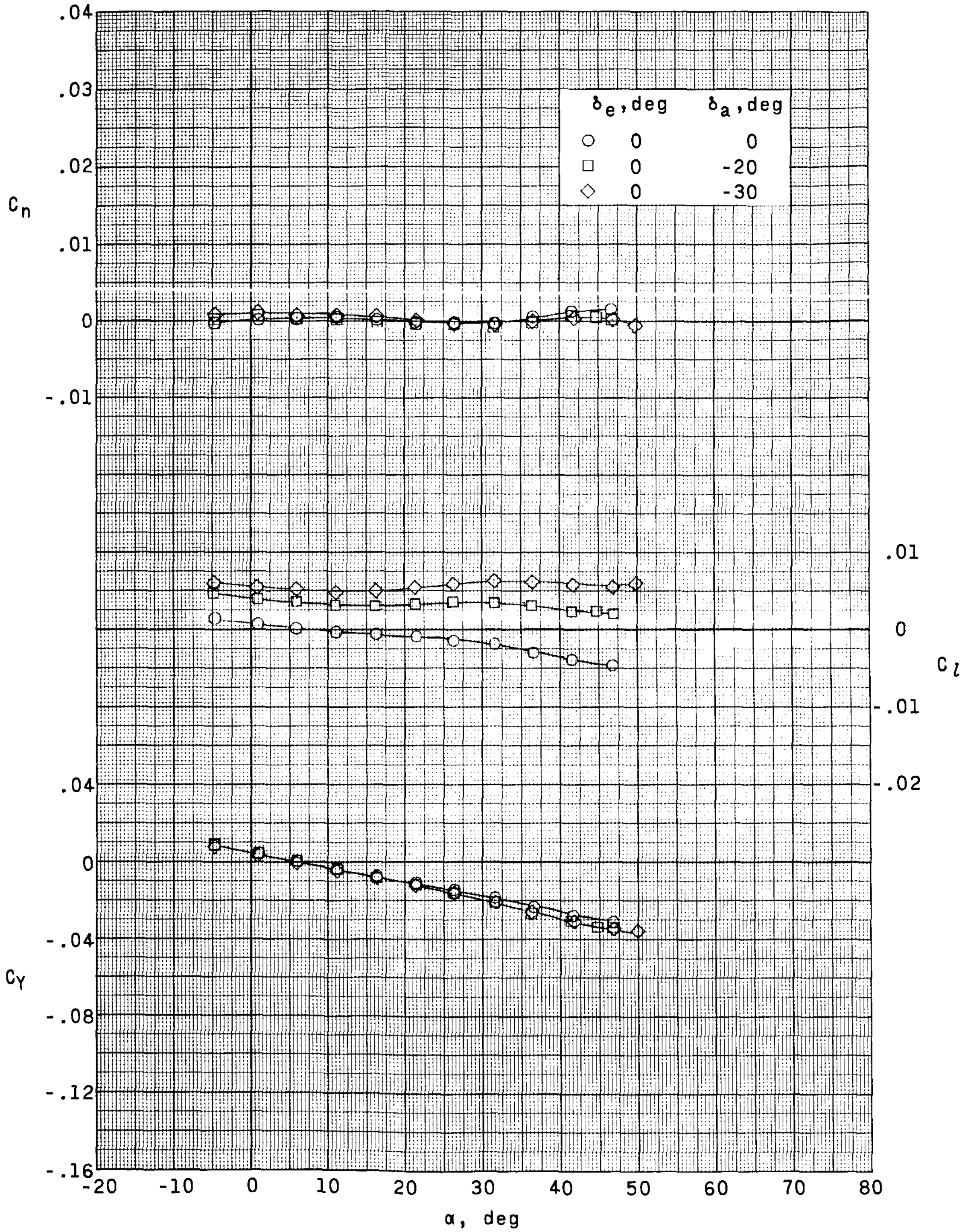
(c) M = 3.95.

Figure 6.- Continued.



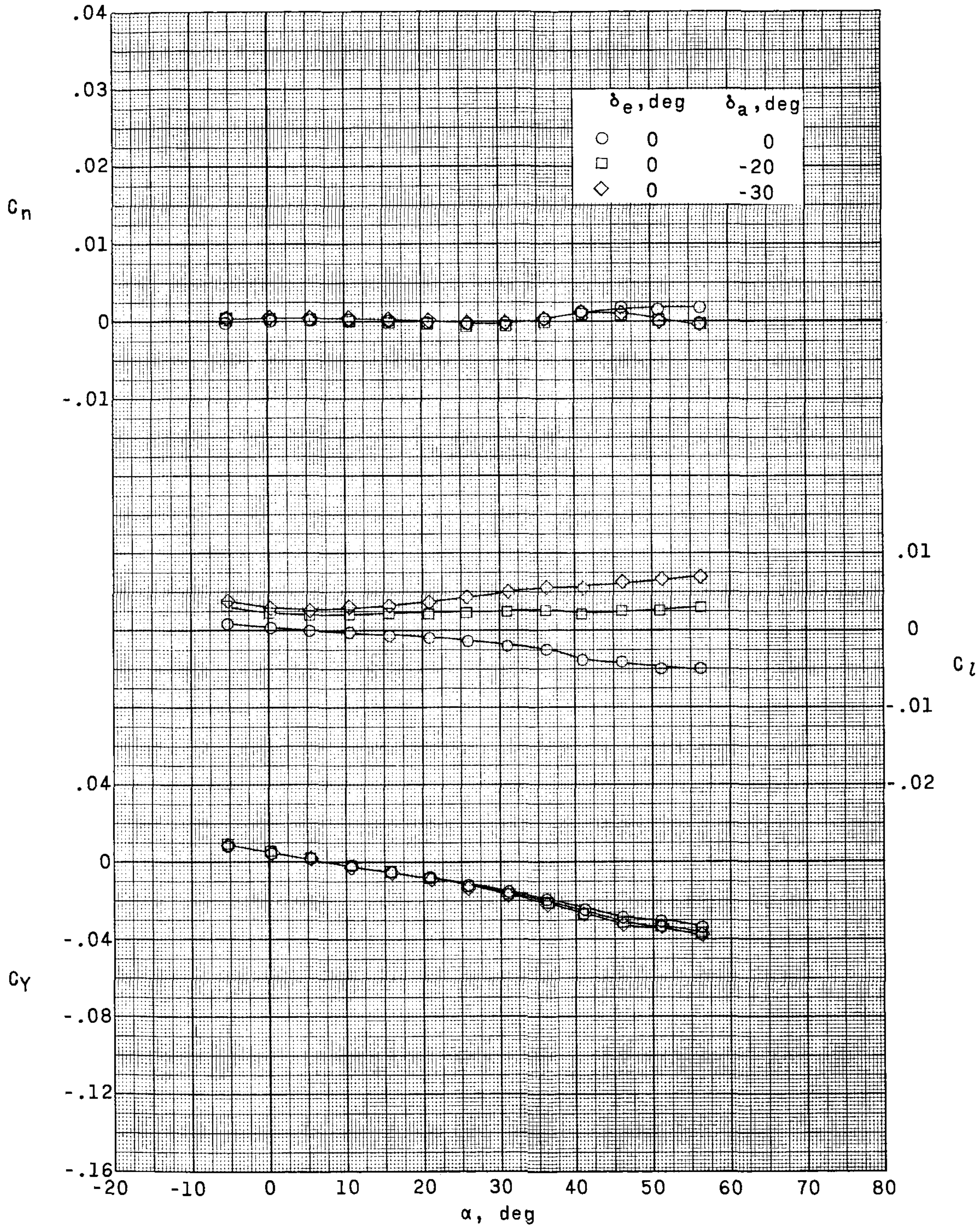
(d) M = 4.63.

Figure 6.- Concluded.



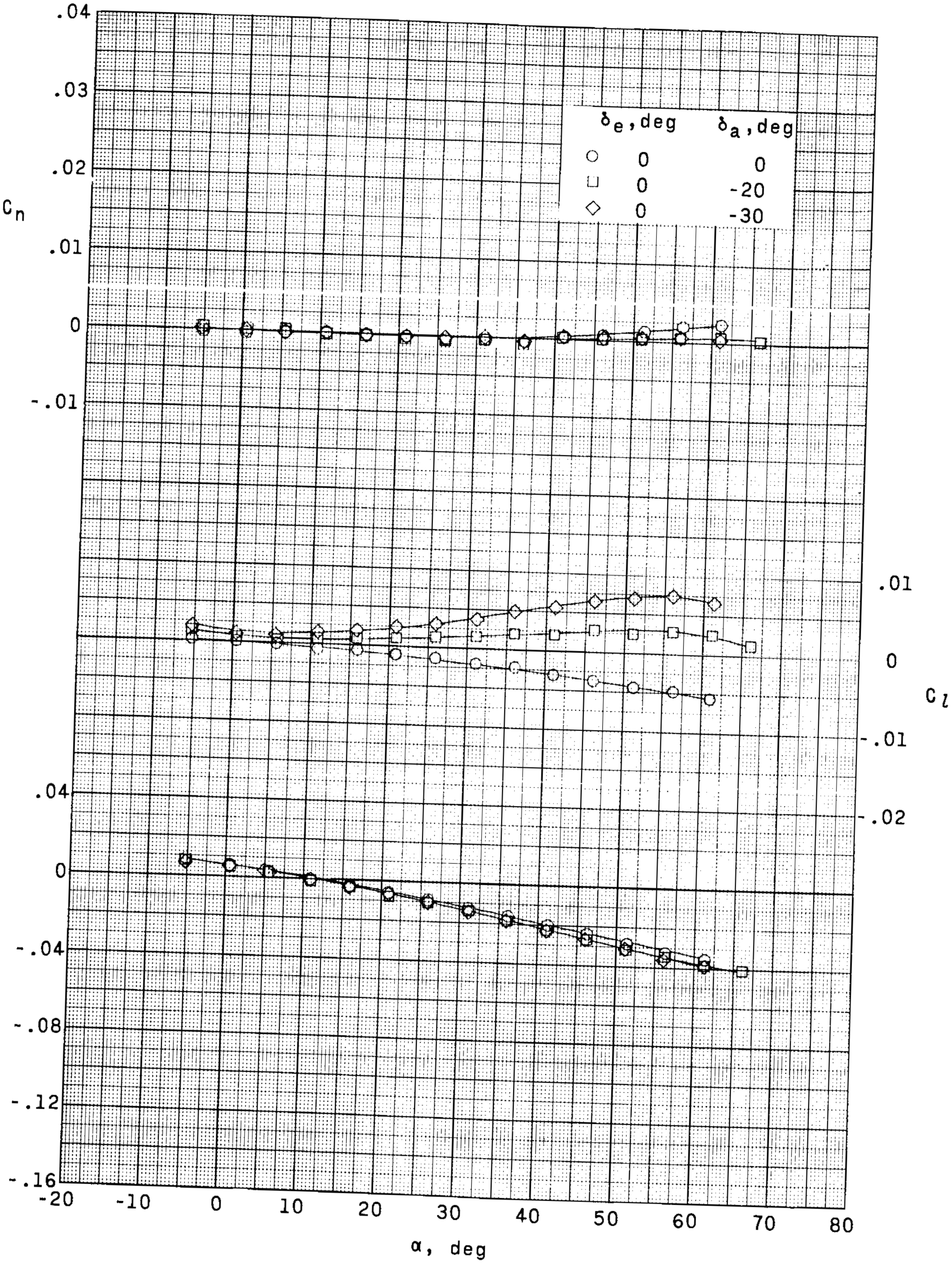
(a) M = 2.29.

Figure 7.- Lateral characteristics of the model with various deflections of the elevons for roll control. $\delta_r = 0^{\circ}$.



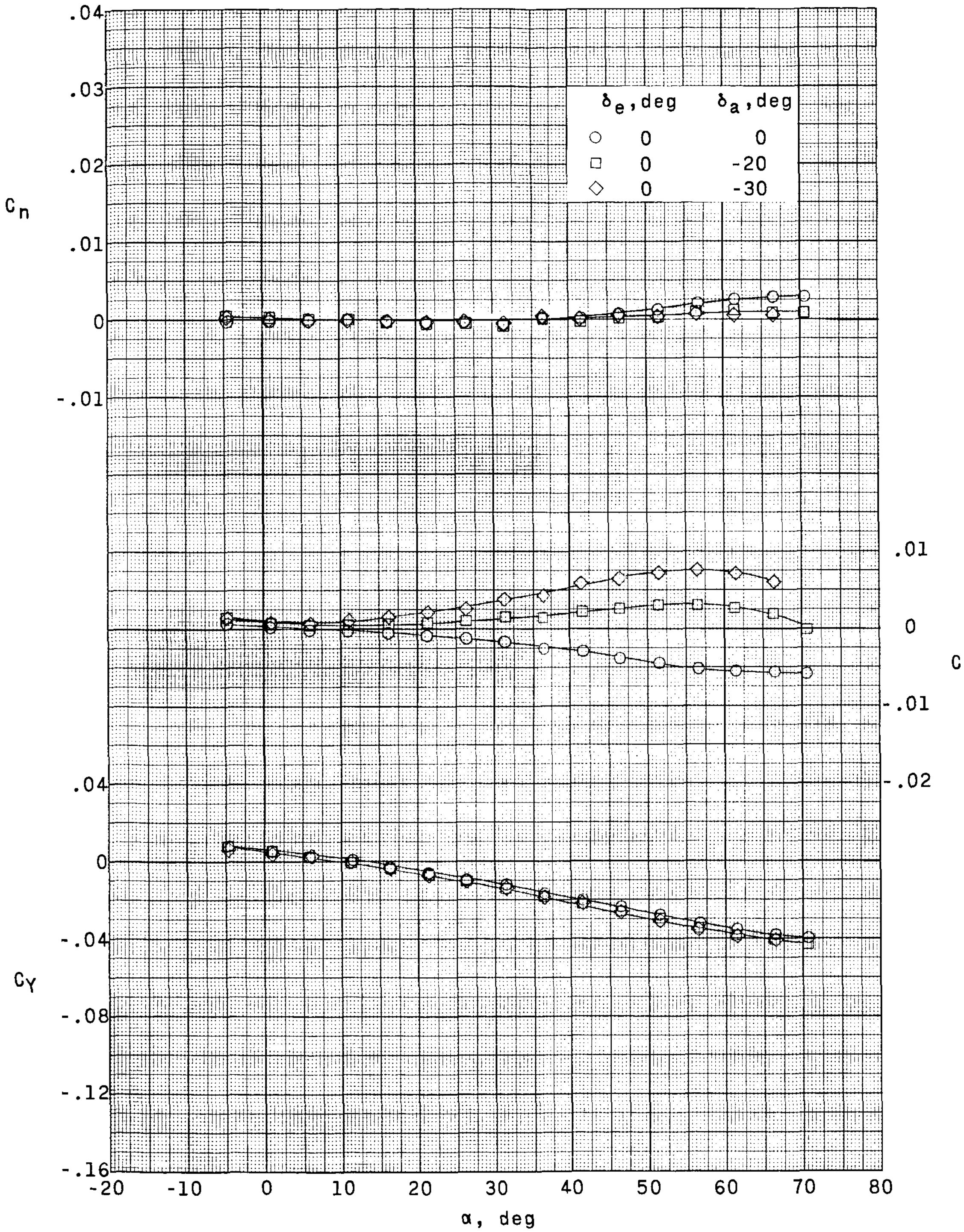
(b) M = 2.96.

Figure 7.- Continued.



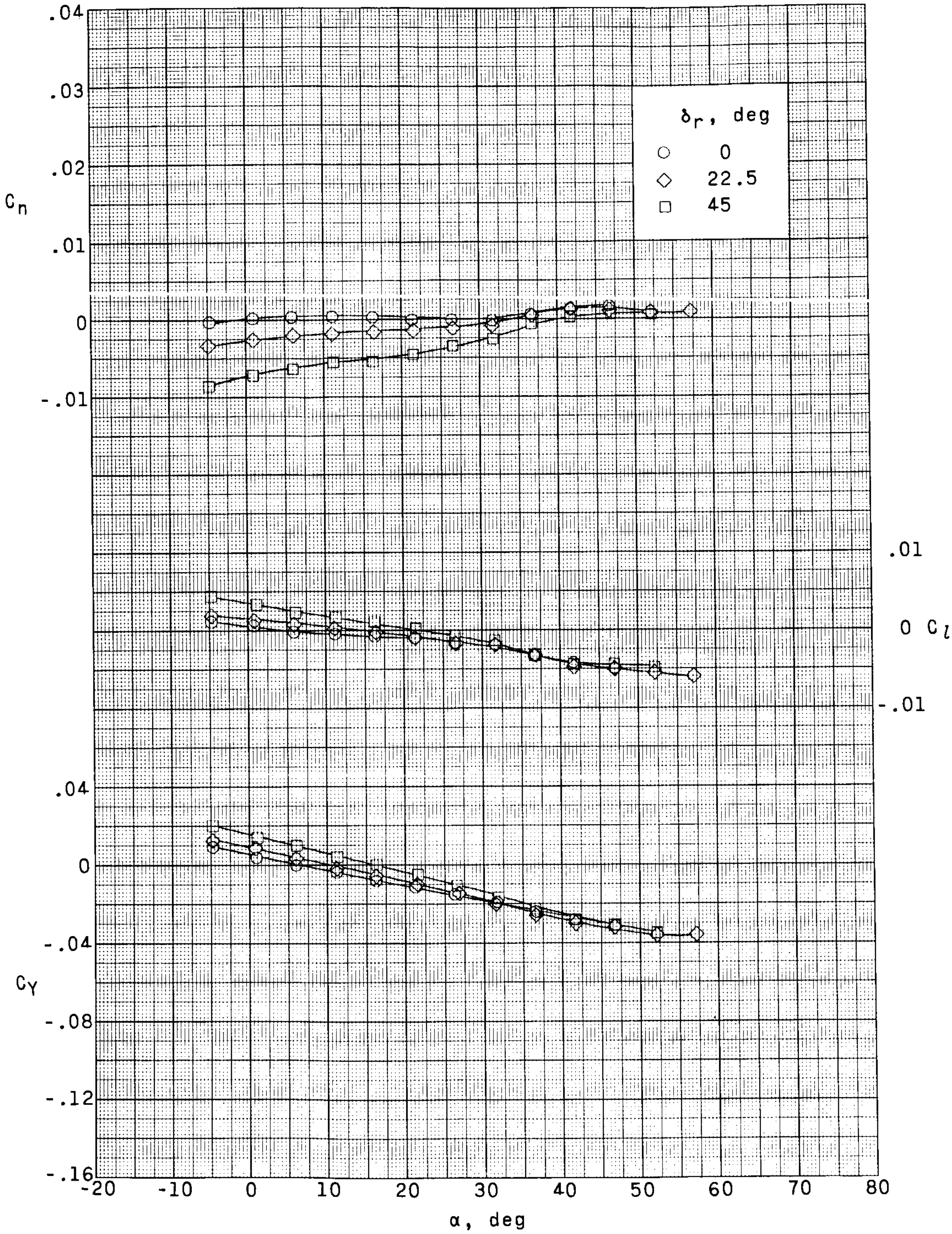
(c) M = 3.95.

Figure 7.- Continued.



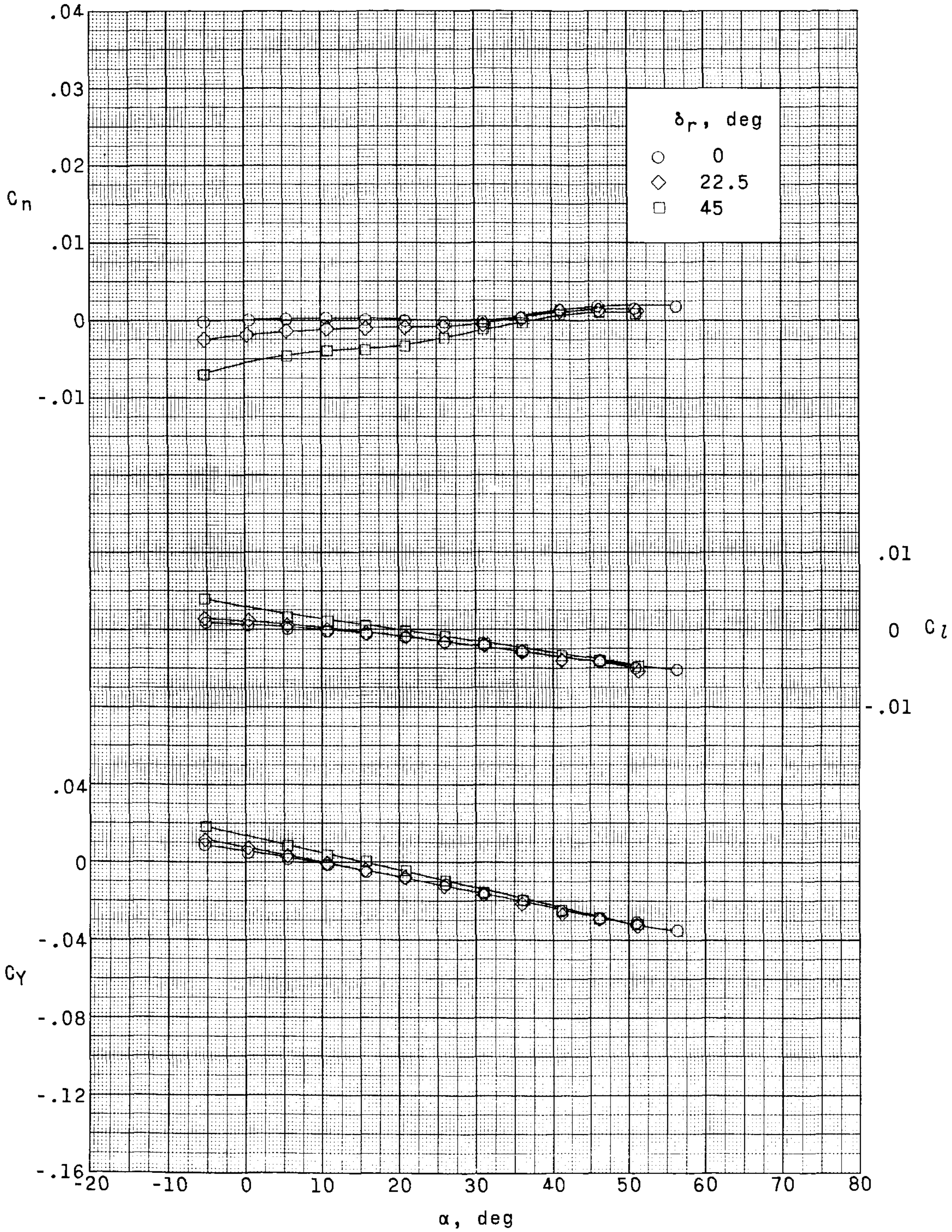
(d) M = 4.63.

Figure 7.- Concluded.



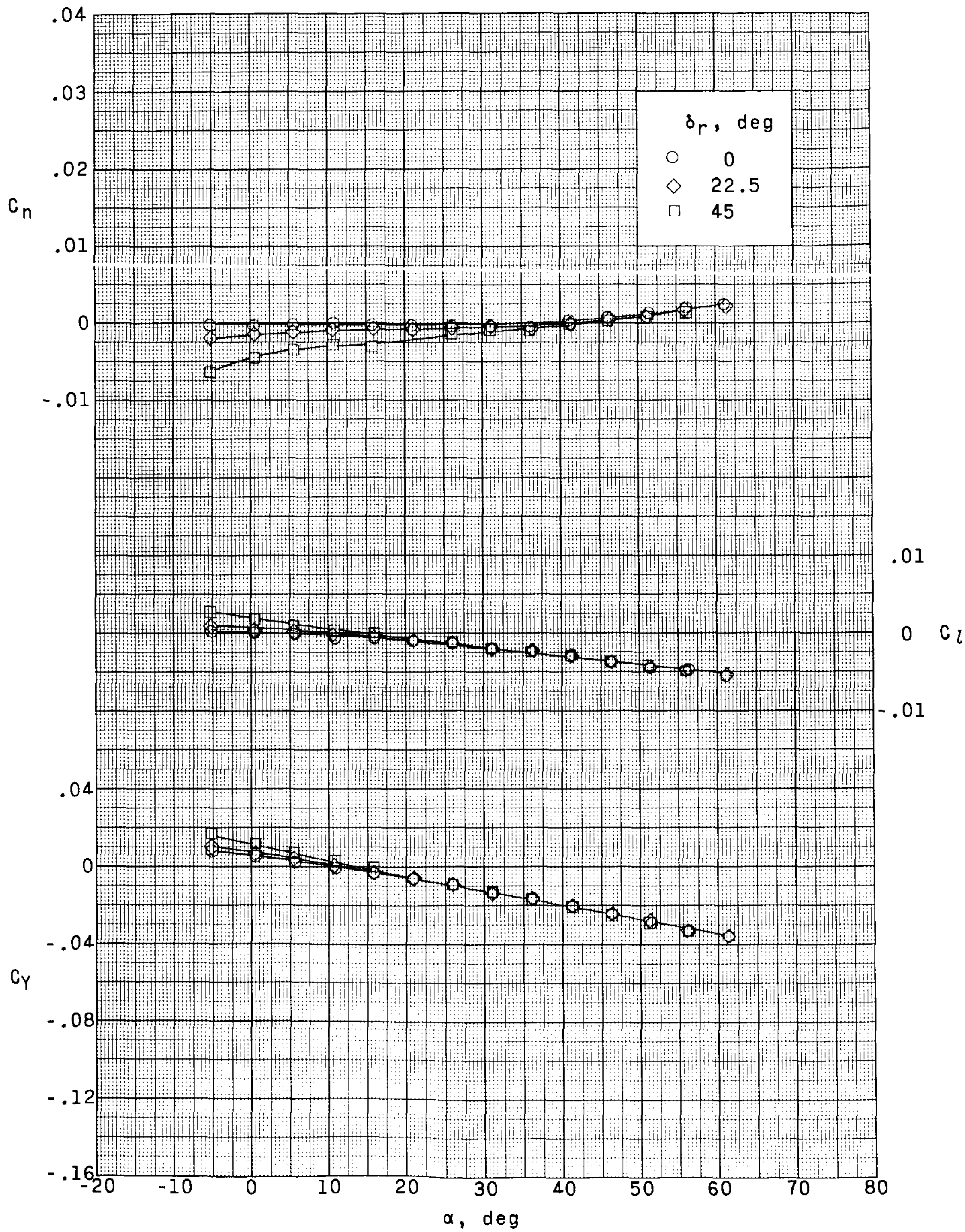
(a) M = 2.29.

Figure 8.- Lateral characteristics of the model with various deflections of the rudder. $\delta_e = \delta_a = 0^{\circ}$.



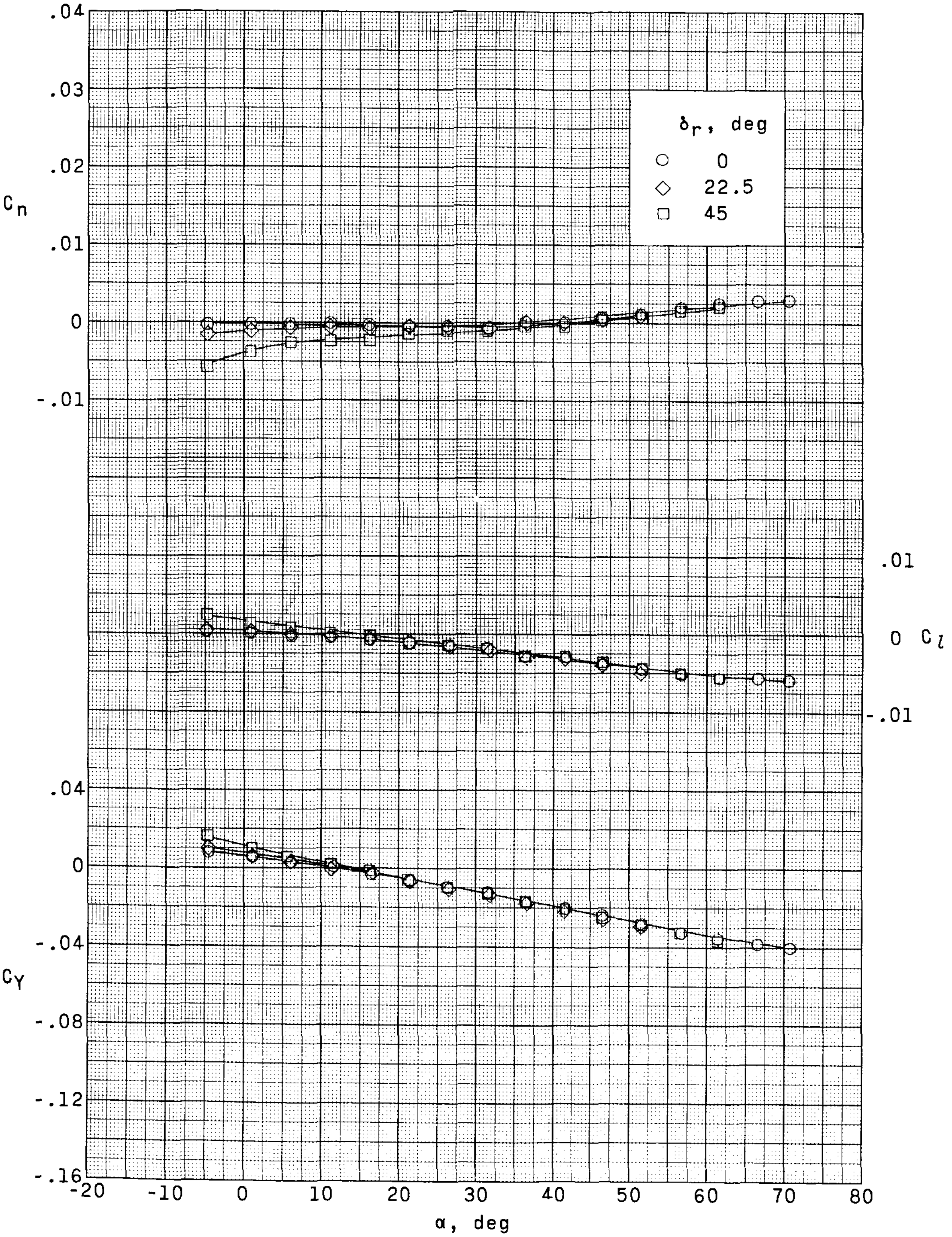
(b) M = 2.96.

Figure 8.- Continued.



(c) M = 3.95.

Figure 8.- Continued.



(d) M = 4.63.

Figure 8.- Concluded.

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Technical information generated in connection with a NASA contract or grant and released under NASA auspices.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

TECHNICAL REPRINTS: Information derived from NASA activities and initially published in the form of journal articles.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities but not necessarily reporting the results of individual NASA-programmed scientific efforts. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION DIVISION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546